MICROMACHINED STIMULATING MICROELECTRODE ARRAYS

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Department of Electrical Engineering and Computer Science
University of Michigan
Ann Arbor, Michigan
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MICROMACHINED STIMULATING MICROELECTRODE ARRAYS

Summary

This contract seeks to develop a family of thin-film stimulating arrays for use in neural prostheses. During the past quarter, work has gone forward in a number of areas. Titanium nitride has been reported to have an even higher charge delivery capability than iridium oxide, and we are exploring its use for stimulating electrodes. We have fabricated passive stimulating probes with TiN sites and are comparing them to probes with IrO sites in terms of their ability to deliver charge to tissue. The TiN sites have been shown to be compatible with the usual probe process and offer a potentially more stable site material that is more commonly available in the microelectronics industry. Charge delivery under pulsed conditions will be reported in the next quarterly report and compared directly with IrO.

During the past term, the first active STIM-3B arrays have been completed, assembled and tested. The arrays are fully functional and are now being readied for in-vivo tests. Several four-probe arrays having 256 sites and 16 parallel channels have been realized. In addition, passive prototype versions of the STIM-2/3 probes have been fabricated and assembled in 3D multi-probe arrays using the STIM-3B mounting hardware. Using flexible interconnect sections between the probe shanks and the circuit area, it has been shown that the circuitry can be folded flat against the cortex to reduce the height of the implant in chronic situations. Finally, the external user interface for the probes has been fabricated in a printed-circuit-board version and has been used with the STIM-2B probes in in-vivo tests. Fine tuning of the external system in both hardware and software is now underway as a basis for supporting the needs of internal and external active probe users.

MICROMACHINED STIMULATING MICROELECTRODE ARRAYS

1. Introduction

The goal of this new contract is the development of active multi-channel arrays of stimulating electrodes suitable for studies of neural information processing at the cellular level and for a variety of closed-loop neural prostheses. The probes should be able to enter neural tissue with minimal disturbance to the neural networks there and deliver highly-controlled (spatially and temporally) charge waveforms to the tissue on a chronic basis. The probes consist of several thin-film conductors supported on a micromachined silicon substrate and insulated from it and from the surrounding electrolyte by silicon dioxide and silicon nitride dielectric films. The stimulating sites are activated iridium, defined photolithographically using a lift-off process. Passive probes having a variety of site sizes and shank configurations have been fabricated successfully in past contracts and have been distributed to a number of research organizations nationally for evaluation in many different research preparations. For chronic use, the biggest problem associated with these passive stimulating probes concerns their leads, which must interface the probe to the outside world. Even using silicon-substrate ribbon cables, the number of allowable interconnects is necessarily limited, and yet a great many stimulating sites are ultimately desirable in order to achieve high spatial localization of the stimulus currents.

The integration of signal processing electronics on the rear of the probe substrate (creating an "active" probe) allows the use of serial digital input data which can be de-multiplexed on the probe to provide access to a large number of stimulating sites from a very few leads. Our goal in this area is to develop a family of active probes capable of chronic implantation in tissue. For such probes, the digital input data must be translated on the probe into per- channel current amplitudes that are then applied to the tissue through the sites. Such probes generally require five external leads, virtually independent of the number of sites used. As discussed in previous reports, we have designed a series of active probes containing CMOS signal processing electronics. Two of these probes have been completed and are designated as STIM-1A and STIM-1B. A third probe, STIM-2, is now ready for a final iteration and is a second-generation version of our original high-end first-generation design, STIM-1. All three probes provide 8-bit resolution in digitally setting the per- channel current amplitudes. STIM-1A and -1B offer a biphasic range using ±5V supplies from 0μA to ±254μA with a resolution of 2μA, while STIM-2 has a range from 0 to ±127μA with a resolution of 1μA. STIM-2 offers the ability to select 8 of 64 electrode sites and to drive these sites independently and in parallel, while STIM-1A allows only 2 of 16 sites to be active at a time (bipolar operation). STIM-IB is a monopolar probe, which allows the user to guide an externally-provided current to any one of 16 sites as selected by the digital input address. The high-end STIM-2 contains provisions for

numerous safety checks and for features such as remote impedance testing in addition to its normal operating modes. It also offers the option of being able to record from any one of the selected sites in addition to stimulation. It will be the backbone of a multi-probe three-dimensional (3D) 1024-site array (STIM-3) now in development. A new probe, STIM-2B, has recently been added to this set. It offers 64-site capability with off-chip generation of the stimulus currents for four separate channels. These channels are organized in four groups so that each current can be directed to any of the 16 sites in its group. Each selected channel can be programmed for either stimulation or recording. On-chip recording amplifiers offer a gain of 50; alternatively, the neural activity can be recorded using off-chip amplifiers interfaced through the normal stimulating channels. This probe is available in both 2D and 3D versions (as STIM-2B/3B).

During the past quarter, we have continued to fabricate passive probe structures for internal and external users. We have also begun a more in-depth look at TiN as a possible alternative to IrO as a site material. Fully functional multi-probe versions of STIM-3B have now been assembled and are ready for testing. Finally, fold-down versions of 3D active arrays representative of STIM-3 have been assembled and shown to represent a feasible way of reducing probe implant height (to less than 500μm). Printed-circuit-board versions of the external probe interface have been received and are now operating with the probes. The results in each of these areas are described more fully in the sections below.

2. Investigation of TiN as a Site Material

Titanium nitride is used extensively as a contact barrier material in integrated circuits and so is commonly available in most IC foundries as well as in our Laboratory. It is used as a passive barrier in the circuit contacts on all of our active probes. It is not clear when used as a site material what the injection mechanism is, but we have begun a serious look at this material to explore its use as a possible alternative to iridium/iridium oxide. The German group at Reutlingen has reported that while the charge capacity is less for TiN than for anodic IrO, the charge delivery capability is greater (by a factor of more than three). We are working to confirm this experimentally. Since the material, like iridium, is highly columnar in structure it may be that titanium in the grain boundaries can react with oxygen from the ambient to switch between different valence states (e.g., 2 and 4), much like iridium does. Sputtered at high pressures, the film is certainly porous and undoubtedly has a very high surface area. We have realized a number of passive probes using TiN sites and have shown that this material is compatible with the overall probe process. The etch-rate in EDP is acceptable, the sites can be formed using lift-off, and the step coverage is adequate for sites that overlap the field oxide of the probe.

This past quarter we have begun a more detailed look at TiN as a site material and have begun direct comparisons with IrO. As reported in the previous contract, TiN sites are comparable to IrO in their low impedance and high charge-transfer capabilities, with the performance of TiN attributed to its highly porous morphology and very high surface area. Preliminary tests have also shown TiN to be better for short-pulse duration and IrO

to be better for longer pulses. A literature search has been conducted in an attempt to better understand these results and in so doing attempt to increase the performance of TiN as a site material.

As noted above, TiN and IrO are both highly porous materials. TiN is highly columnar, whereas IrO pores are more tortuous. Even though a porous material increases surface area, it also creates problems with the resistivity associated with the electrolyte and the matrix[1]. Because the TiN pores are more open to the electrolyte than those in IrO, there is less impedance between the electrolyte and the surface, increasing the availability of charge from the double layer at t=0. The IrO surface, on the other hand, because its pores are more enclosed, traps the charge and causes repulsive interactions which hinder immediate charge transfer but result in more sustained capacitance and better performance for longer pulses. During the next quarter, we plan to examine the TiN films to see if oxygen in these films plays a role in the impedance and charge-transfer behavior. We also plan to confirm the etch rates of this material in EDP and do direct comparisons under pulsed conditions of TiN with IrO.

3. Active Stimulating Probe Development

The active stimulating probe development has progressed to the long-term testing stage of the STIM-2B probes. We have also begun work in the assembly of the STIM-3B probe arrays. Also, structures have been fabricated to allow preliminary tests to be carried out on the future high-end 3D-probe array, STIM-3.

STIM-2B

STIM-2B is a second-generation probe, a version of our simplest active stimulating probe, STIM-1B. As noted earlier, STIM-2B is a four-channel, 16-shank, 64-site probe which routes four externally generated stimulus signals to 1-of-16 sites per channel. The fabrication of the CMOS circuitry has been completed and the digital functionality of the circuitry has been verified through testing of the different operating modes for the probe, including power-on reset (POR), site selection, and amplifier selection. Testing of the analog amplifier has demonstrated that it too works quite well *in-vitro*, though *in-vivo* operation has been problematic due to the large DC drifts at the iridium sites. This will be corrected in the next iteration through the use of lower-resistance input clamps across the amplifier inputs.

The STIM-2B probe provides an important tool for performing some very important experiments by allowing acute and chronic stimulation access to a relatively large volume of neural tissue without mechanically repositioning the probe. This capability is realized by utilizing a 20b shift register to load four 4b site addresses which are decoded by a 1-of-16 NAND-type decoder to connect the desired site to an analog

[1] S. Sarangapani, B. V. Tilak, and C. P. Chen, J. Electrochem. Soc., 143, 3791 (1996).

input/output pad through a large CMOS pass-gate transistor, thereby allowing the 'steering' of externally generated currents to the addressed site. A recording function is included and is addressed by a fifth bit included with the 4b site address. This fifth bit selects between stimulation mode and recording mode by selecting either a direct path to the I/O pad from the site (stimulation input) or a path through an amplifier for recording from the same site (recording output). Each I/O channel has its own dedicated amplifier so that the functionality of all of the channels is independent of each other except for the up-front data input circuitry.

As we have reported previously, we have used the STIM-2B probe in acute experiments for both stimulation and recording. We have been able to successfully demonstrate the capability to selectively stimulate neural activity in an area local to a given stimulation site. We have also demonstrated the ability to record neural signals with the STIM-2B probe. These two combined capabilities are what we feel make this probe such a valuable tool in neuroscience research and the basis for neuroprosthesis use.

The current work with the STIM-2B probes is now moving into long-term *in-vitro* testing. As soon as the cable terminator/probe connector, discussed below, is completed, we will be starting long-term pulse testing to see that the encapsulation layers, the iridium sites, and the circuitry all perform as expected in a saline environment over extended periods of time. In order to observe any changes in the iridium sites, we plan to take surface profile scans of the iridium sites with a Zygo interferometer, optical and SEM photographs and CV measurements before starting pulse testing and at intervals during the testing. We also plan to monitor the probe power supply lines during testing in order to observe any leakage current if it should occur, whether through the dielectric encapsulation layers or through the epoxy used to encapsulate the bonding wires. We also plan to do some comprehensive comparisons of the site activation techniques that we have tested on a small scale up to this point, parallel activation of all sites or serial activation of individual sites. We plan to do activation of sites in parallel and then observe the individual CV characteristics of the sites and see how much variation there is across the array of sites. We have used parallel activation with good success in a limited number of cases, as reported previously, but it would be better to have a larger number of samples to confirm our results. We do have the option of activating the sites in parallel to a predetermined level and then individually activating the sites to their final more closely matched levels. This would still be far superior to individually activating all sites, given the amount of time required for activation.

We are in the process of making design changes to the STIM-2B probe in order to iterate the design per the new contract schedule. There are several changes that we plan to make to the STIM-2B/3B probe design. The first change involves simply changing the size ratio of the PMOS/NMOS transistors in the level shifters. The level shifters change the logic levels of the input signals from 0V-5V to the -5V to -5V range needed to operate the site selectors. As discussed in previous reports, the level shifters tend to operate slower than desired when operated at normal ±5V supplies. Currently, if speed is absolutely necessary, this problem can be overcome by adjusting the supply voltages,

which for present use is okay, but is not desirable for a standardized device. We also plan to change the amplifier design to a simpler more robust design, similar to what is used on our recording probes. The goal is to make the STIM-2B/3B design as simple and robust as possible with respect to both the fabrication process and use. We also plan to include a design that would have an eight-shank, 8-site per shank configuration. We are also considering a four-shank, 16 site per shank configuration that would give access to deeper structures. Whether we go to a four-shank version or not, we may still include some versions of the probe with longer shanks for the purpose of gaining access to deeper structures. These are simply changes in the layout of the shanks from the current 16-shank version.

STIM-3B

STIM-3B is a three-dimensional (3D) probe that is an extension of the 2D probe, STIM-2B, and is set up to allow use as a device in chronic experiments by virtue of a platform configuration with an integrated ribbon cable for connection to a percutaneous plug. There are no significant differences in the actual probe designs. The main differences are structural modifications to allow connection to a 3D-platform assembly and a few minor circuit enhancements to facilitate the addressing of multiple probes in a 3D array.

Like STIM-2B, the STIM-3B probe is expected to provide an important tool for performing important experiments by allowing the acute and chronic stimulation access to a relatively large volume of neural tissue without mechanically repositioning the probe. STIM-3B is a four-channel, 16-shank, 64-site probe which routes four externally generated stimulus signals to 1-of-16 sites per channel. Again, a 20b shift register is used to load four 4b site addresses which are decoded to connect the desired site to an analog input/output pad through a large CMOS pass-gate transistor and provide access to the addressed site. A fifth bit in each address group selects either stimulation mode or recording mode. In order to allow addressing of multiple probes in a 3D array, STIM-3B has an extra 4b serial input shift-register which, when the bits are set, connects the corresponding I/O channel of the probe onto a common I/O bus on the platform. All of these extra registers in a STIM-3B array are connected in series via platform leads to form an extended or virtual register. The virtual register enables all of the probes of a 3D array to be addressed with only two address lines, a channel enable address line and a site address line. This architecture has been discussed in detail in previous reports.

Rather than waste area on the active probe mask set, the STIM-3B 3D structural pieces were designed on a completely separate mask set that only required six masks and was essentially the same fabrication process as used for passive probes except that there are no site or pad masks; instead, there is a single beam/pad electroplating mask. The electroplating mask is used as the final step to form the beam lead interconnects and pads on the platforms after the field etch has been done. The conductor mask was designed with the polarity reversed from what it would normally be for a passive probe so that it could be used in a lift-off process for metal conductors instead of polysilicon. The first

platforms were still fabricated using polysilicon as the interconnect (patterned by image reversal), but we anticipate using lower resistance metal interconnect layers on future platforms.

We have several different platform designs that were fabricated: a 16-probe platform and three 4-probe platforms. The four-probe platforms include a version that has all probes facing the same direction, a version that has all probes facing towards the centerline and a version that has all the probes facing the same direction but with the ribbon cable exiting from the side of the platform instead of the end as on the others. The platforms all have integrated microfuses to allow the number of probes included on the platform to be varied, i.e., a given platform can be only partially populated by probes. If a fuse is not 'blown', the data will be shunted to the next probe slot without being routed through the probe that would have been in the current slot.

The current work on the STIM-3B probes is focused on final assembly and testing. The setup that was previously developed for the assembly of 3D recording arrays is being utilized for assembly of STIM-3B. Several new jigs for the larger array sizes have been made and successfully used to assemble probe arrays. We are working on fabricating some new assembly jigging which when completed will make assembly of the 3D arrays easier and faster. We are also changing some of the assembly setup: the 3-axis micromanipulator stage for placing array pieces into position is being upgraded to a more rigid design that allows less movement in the stage due to simply touching or turning the positioning knobs. This upgrade alone will improve the assembly process.

An optical photograph of an assembled four-probe 3D array is shown in Fig. 1. In the photograph, the four 2D probes can be seen positioned in the platform with the two spacers in place on both ends. Small drops of epoxy at each corner hold the entire array together. The upper part of the array will be completely potted in epoxy prior to implantation in order to insulate the beam-lead transfers. The beam leads on the probe outriggers and the mating pads on the platform for the orthogonal lead transfers can be seen on either end of the array. The ribbon cable interconnect for power and signal input/output can be seen exiting the platform from the end. The disk on top of the four probes is simply a micromachined circle fastened by a drop of epoxy in order to have a flat surface to hold onto with a vacuum pick. A closer view of the array can be seen in the SEM photograph of Fig. 2. By lining up the shanks, Fig. 3 gives a better feeling for how many sites are actually in the entire array, a total of 256.

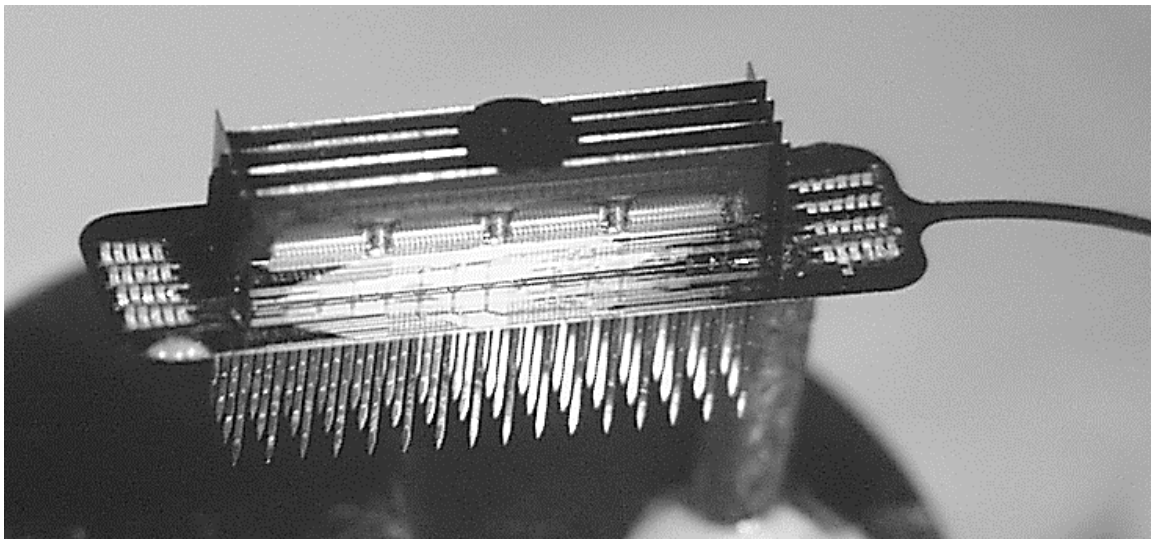

Fig. 1**:** An optical photograph showing an assembled 4-probe STIM-3B array with the integrated ribbon cable for power and signal input and output.

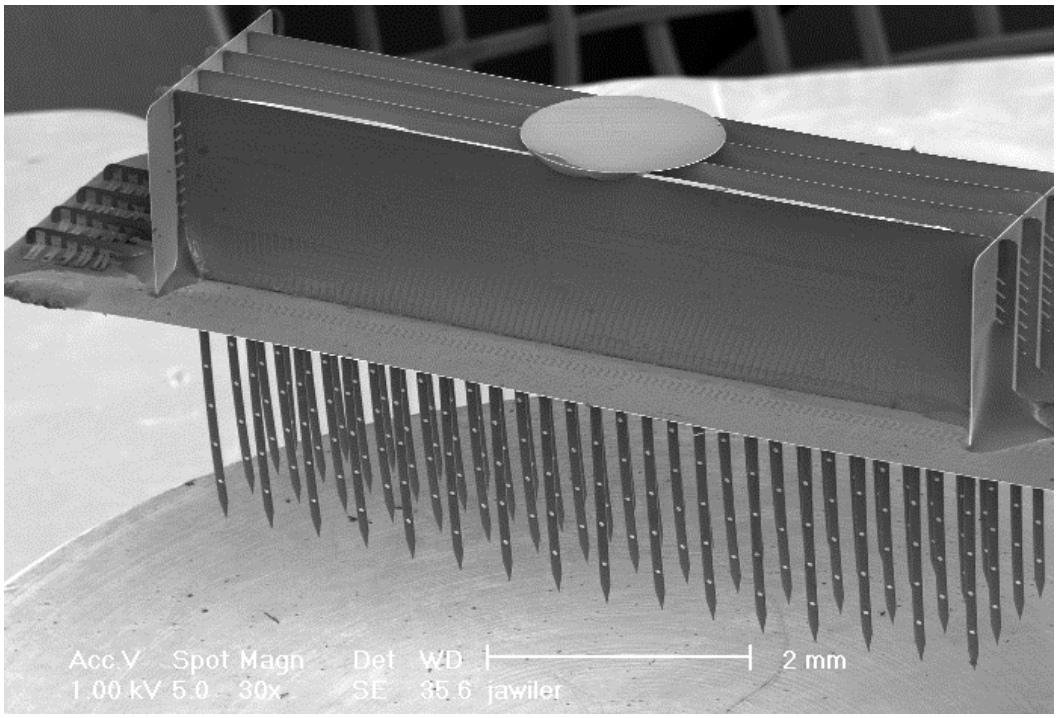

Fig. 2: A SEM photograph of the assembled STIM-3B array with the spacers, the disc for vacuum pick handling and the beam-lead transfers clearly visible.

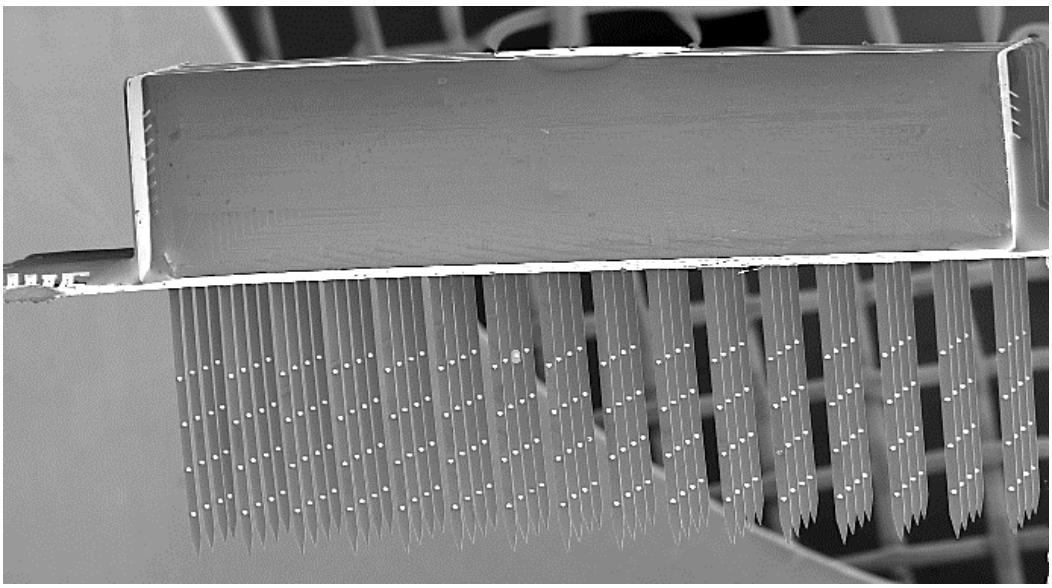

Fig. 3: A SEM photograph of an assembled STIM-3B array with all of the sites clearly visible, a total of 256.

STIM-3 Test Structures

STIM-3 will be a high-end active CMOS 3D stimulation array with on-chip current generation, minimal lead count, low profile, and up to 1024 sites. In order to prepare for the final design and fabrication of this system, several test probe structures were included on the STIM-3B 3D platform mask set. These structures were intended to test the feasibility of folded-down circuitry on a probe for reduced height of a 3D probe array. The structures were also intended to test how well the circuit area could be protected from undercut using properly designed dielectric bridges. Figure 4 shows an SEM photograph of one of the test probe structures viewed from the backside. The slotted arm link with the standard STIM-3B spacer can be seen on the left. Multiple dielectric bridges were included between the flexible interconnects in order to provide protection for the front edge of the circuitry which in the past has been susceptible to undercut due to the early breakthrough of the backside etch plane in the wider areas between the shanks or in this case the flexible interconnects. The dielectric bridges between the flexible interconnects may or may not break off during the etch-out process (some can be still seen in Fig. 4), but it doesn't matter in this case. Four different test structures were included: one with long straight flexible interconnects, one with short straight flexible interconnects, one with long angled flexible interconnects and one with short angled flexible interconnects. "Straight" and "angled" refer to whether the flexible ribbon interconnects are aligned with the probe shanks (and the <110> direction in the silicon or not.

The different variations were included in order to test if either the straight or the angled flexible interconnects would etch out better and to test if there is one configuration that folds down better than the other. As it turns out, all of the different configurations etch out quite well and the circuit areas all remained well protected even with a 1/2 hour over-etch. The length of the interconnects becomes important when considering how tightly the probes can be bent over. A longer interconnect would presumably allow a larger radius of curvature and therefore make it easier to bend to the necessary angle. A shorter interconnect would allow for a smaller layout, a more compact design, and a smaller footprint when in the folded position, but would have a greater risk of breakage. The goal is to use the shortest interconnect with a reasonable safety margin from breakage.

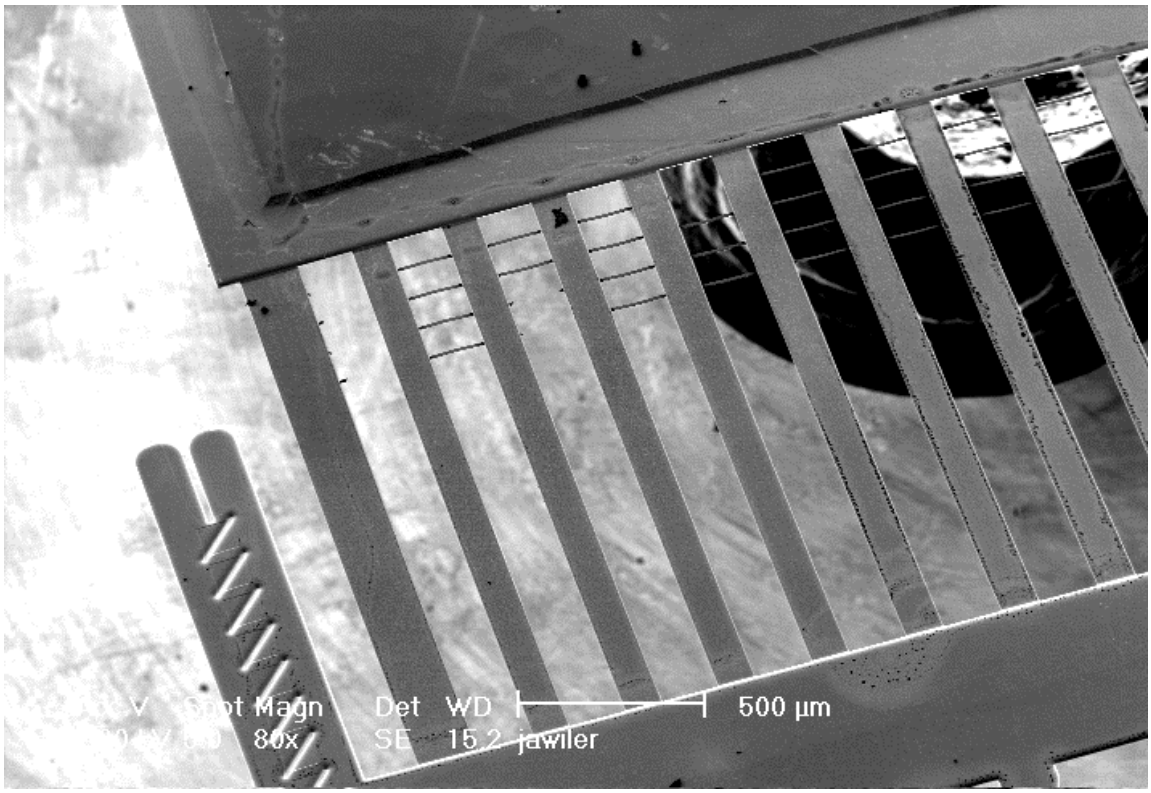

Fig. 4: An SEM photograph of a STIM-3 test probe structure as viewed from the backside. Note several of the dielectric protection bridges remain between the interconnects. The slotted spacer arm can be seen on the left.

Two of the designs were assembled into a platform and are shown in Fig. 5 sitting on the assembly jig next to a paper clip. The particular probes used in this test were etched all the way to the etch-stop and to the dielectrics in the circuit areas, which allow visibility through the circuit area 'windows'. The two probes have different length interconnects and the orientation of the longer version is at an angle while those of the shorter version are straight. The shorter, straight interconnect version can be seen in Fig.

6, where the array is viewed from the opposite side. Figure 7 shows the two probes being bent over in one direction, and Fig. 8 shows it being bent the opposite direction. A broken long-angled interconnect is visible in the upper portion of the array, but this breakage occurred prior to assembly due to mishandling. All of the short interconnects are clearly visible and all remained intact after bending the probes both directions. In both cases, the probes can be bent down to the surface of the jig, and more significantly, their height is less than that of the spacers. The spacers are from the current STIM-3B design. Thus, we can see that we should be able to use this technique to decrease the height of the overall assembly.

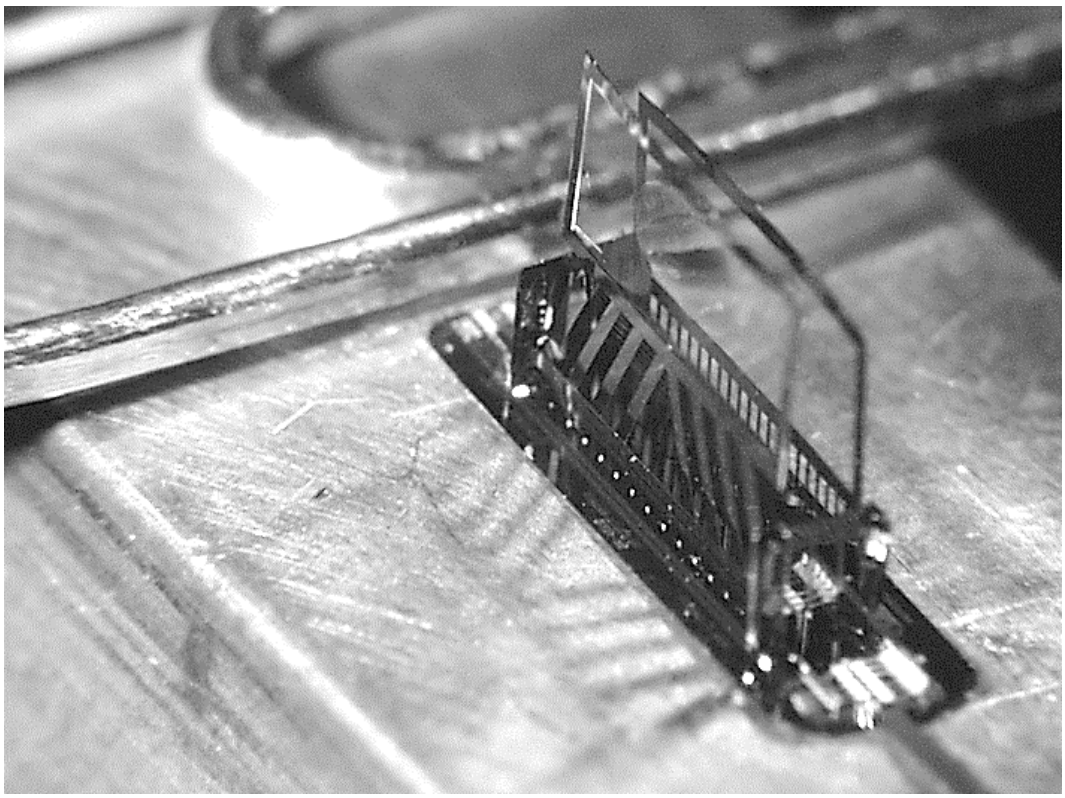

Fig. 5: This photograph shows two versions of the folded-down test structures assembled in a platform with the long-angled interconnect version in front. The circuit areas of these particular test probes have been etched to the transparent dielectric layers allowing better visibility of the assembly.

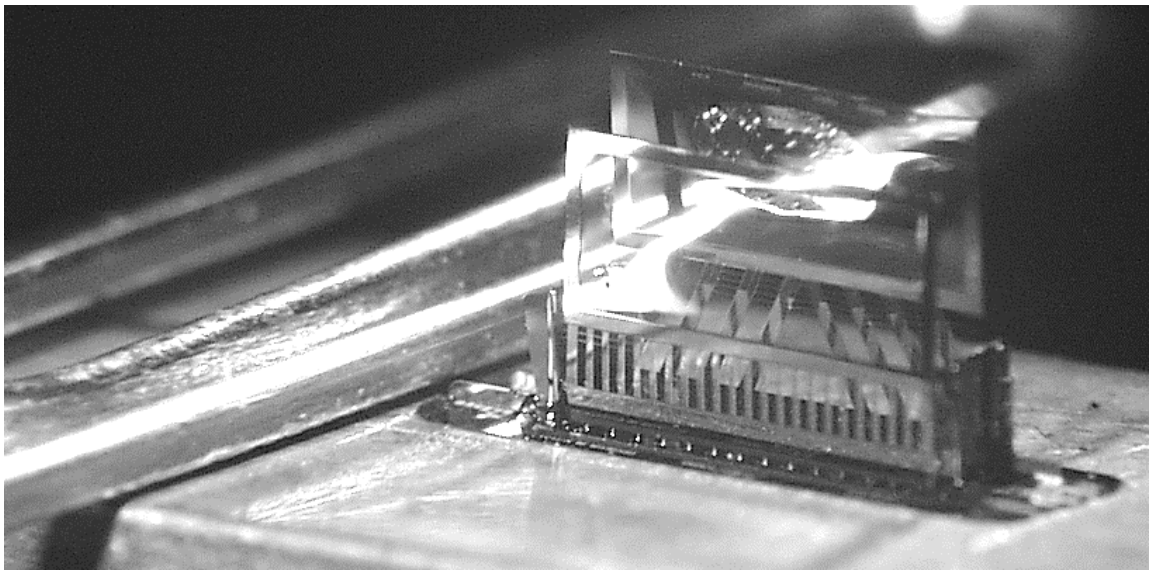

Fig. 6: This photograph shows two versions of the fold-down test structures assembled in a platform with the short straight interconnect version in front. The circuit areas of these particular test probes have been etched to the transparent dielectric layers allowing better visibility of the assembly.

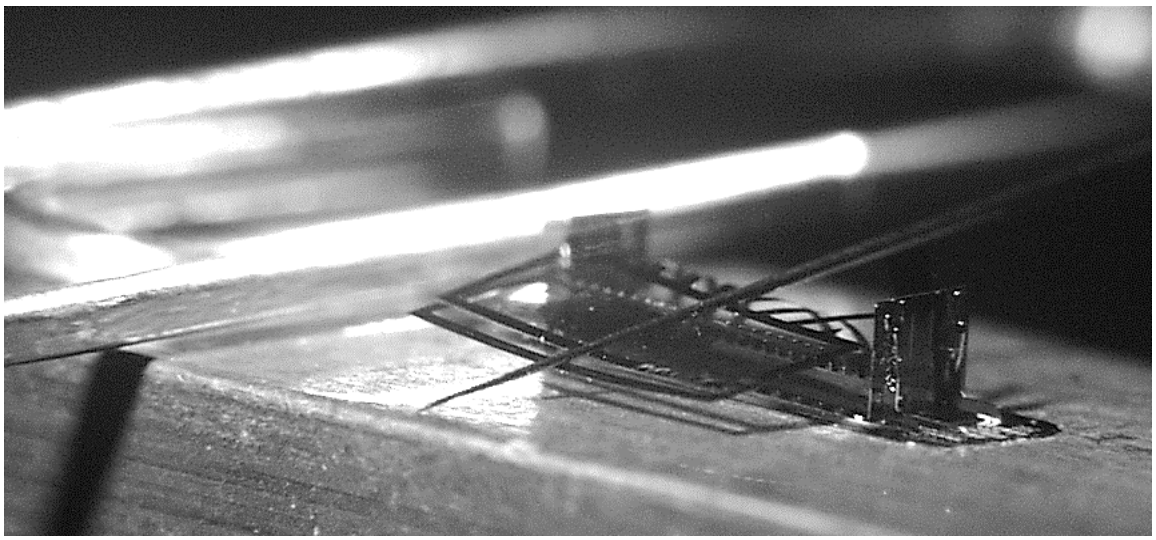

Fig. 7: A photograph of the two test structures folded down such that they are almost touching the surface of the jig.

Figure 8 does show that the longer interconnects result in a much larger footprint, which is not desirable. For this reason, we want to keep the interconnects as short as possible. The particular folded-down configuration shown in these two figures is not particularly desirable because of the way the circuit area sticks out to the side of the platform. In the STIM-3 array, it is expected that the probe circuit area will fold down

over the part of the platform that contains the array addressing circuitry etc., which will likely be hybrid. Thus, in the intended application, the lateral extent will not be as obtrusive as these test structures would make it appear. The results of these tests indicate that the shorter interconnects are long enough to achieve complete folding without breakage and may even be able to be shortened still further.

In summary, we are starting long-term testing of the STIM-2B probes. We have successfully assembled the 3D STIM-3B probe array. The tests of the folded-down circuit area in preparation for the STIM-3 array have demonstrated the viability of this technique to reduce implant height. In the coming quarter, we plan to perform long-term testing of the STIM-2B probes. We also plan to perform *in-vitro* and hopefully *in-vivo* testing of the STIM-3B 3D array. Iteration of the STIM-2B/3B designs is expected to be completed and should go to fabrication on schedule.

4. External Stimulating Interface System

We have designed and constructed an interface system for active stimulating probes, as described in previous reports. The printed circuit board realization of our hardware design has now been fabricated (see Fig. 9) and tested. This version of the system operates much faster and supports a probe bit rate up to 9.5Mbits per second, with provision for dividing this down by factors up to 256. The system is operated remotely via a serial cable link to a personal computer. The complete system is shown in Fig. 10. Graphical software has been developed for easy use of the system and a command-line interpreter is included in a separate window, which allows for fine-grain control over the remote system. Whereas the graphical component of the interface is intended as an easy-to-use method for performing common functions, the command-line interpreter can be used to effect any other function not supported by the graphical interface.

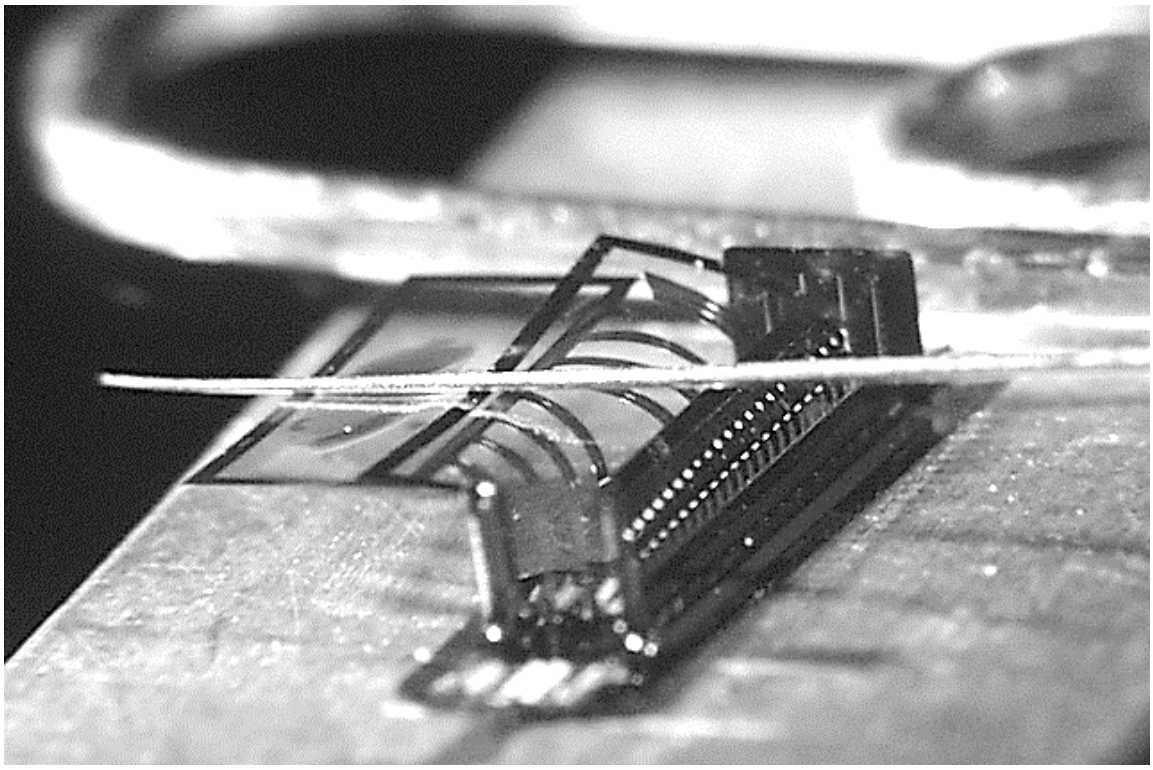

Fig. 8: A photograph of the two test structures folded down in the opposite direction to that of Fig. 7. The short, straight interconnects are clearly visible and all intact.

In testing the prototype board, it was found that the a standard serial cable used to connect the output of the printed circuit board to the input of the probe did not provide as much cross-talk suppression as we needed since the digital and analog lines all run through the same cable. A solution to the problem was to utilize a Sun Video Cable as the cable connecting to the location of the probe. The Sun Video Cable has three shielded mini-coax lines which are used for the high speed data and clock lines and the remainder of the signals are carried over shielded twisted-pair lines. The use of the Sun Video Cable has solved several problems, but we have also found two more problems when used with the STIM-2B/3B probe design. First, we need to design and fabricate a cable termination/probe connector board, though some version of this would have likely been necessary no matter what cable were used. Secondly, a problem arises when it is necessary to externally drive current stimulus pulses. The shielded cable provides good noise and cross-talk protection, but the shielding adds a significant amount of distributed parasitic shunt capacitance between the current driver and the ultimate target, the probe site. In a 6 ft. Sun Video Cable, the capacitance of the lead to the grounded shielding was measured to be approximately 200pF, which is about 10% of the normal capacitance seen in a 1000μm^2 activated iridium site. If the length of the cable is doubled, as may be required for normal use through the wall of a shielded experimental booth, the shunt capacitance rises to 20% of the site capacitance. This can have a very significant effect in

diminishing the ability to deliver short precisely-controlled current pulses to the probe site. A solution to this problem is discussed below.

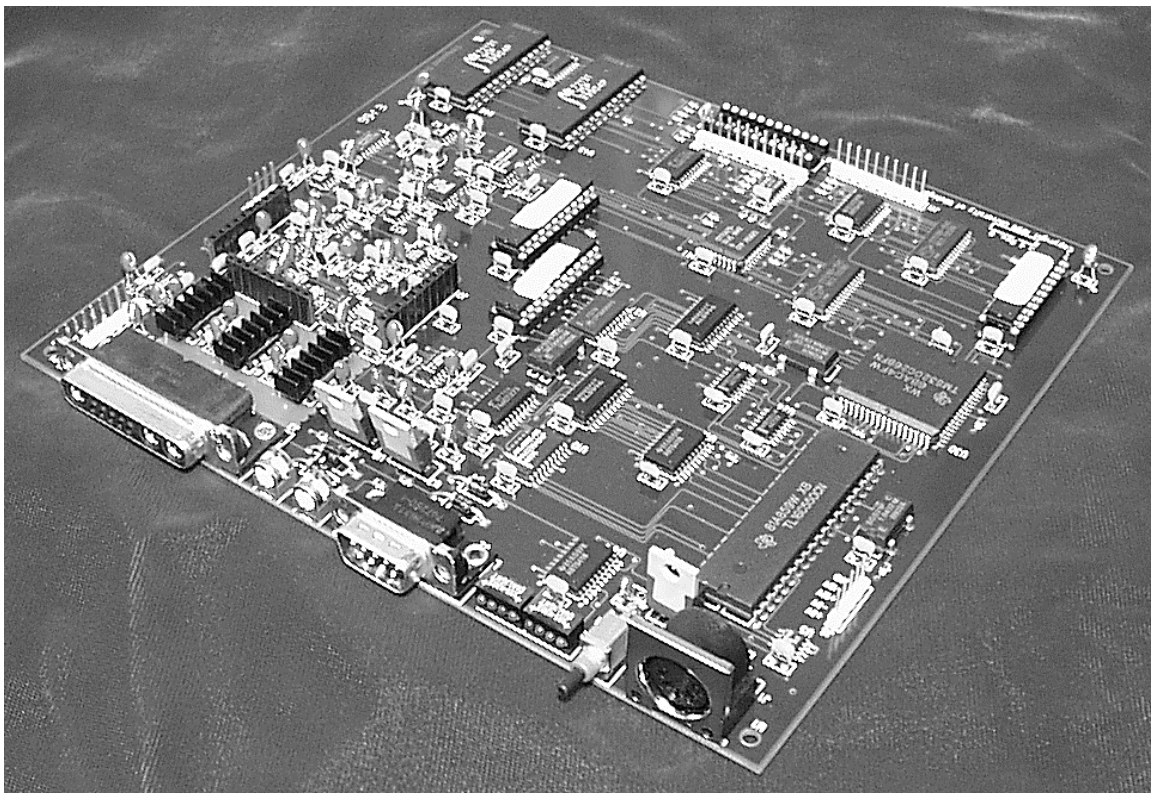

Fig. 9: The printed circuit board realization of the external interface system hardware.

The custom interface board currently includes only a D/A converter with a voltage output. The board was designed with the capability to plug in a voltage-to-current converter daughter card. The reason for this was because of the difficulty experienced in designing a circuit with current monitoring feedback that will perform with the response times desired. The plug-in daughter board design allows the voltage-to-current converter to be easily upgraded as the design is improved. Thus the current configuration makes it relatively easy to solve the problem of the parasitic shunt capacitance. Since a cable termination/probe connector is needed anyway, the voltage-to-current converter will simply be placed out on the connector where it is much closer to the probe and the cable shunt capacitance can be quickly charged with a high current voltage driver. Figure 11 schematically shows the initial problem and the current solution.

Since its inception, the circuit on the connector concept has evolved with several additional circuits being desired to provide various features. First, the STIM-2B/3B probes include a mode that disconnects all sites so that current leakage can be tested. Theoretically, when held in the disconnected state, there should be no current flowing through the probe's CMOS circuitry or to the tissue. Thus, monitoring the current flow

through the power supply leads to the probe will indicate the amount of leakage current flowing. The circuitry to implement this feature will be included on the connector. Secondly, the capability to handle and process the recorded signals was not included in the custom interface board, since that would have required integrating two entire systems (recording and stimulation). Integrating the two systems was a problem we were not ready to tackle due to the complexity of the noise issues related to mixing low-level recorded analog signals and high-speed digital processing noise related to the stimulation circuitry. The ability to record from certain stimulating probe designs is very useful. We are thus including circuitry and signal leads on the connector to give us the ability to pull recorded signals off the probe through a separate system. The low input bias current buffer amplifiers are simply directly connected to the analog I/O leads (stimulus current leads) and monitored as desired.

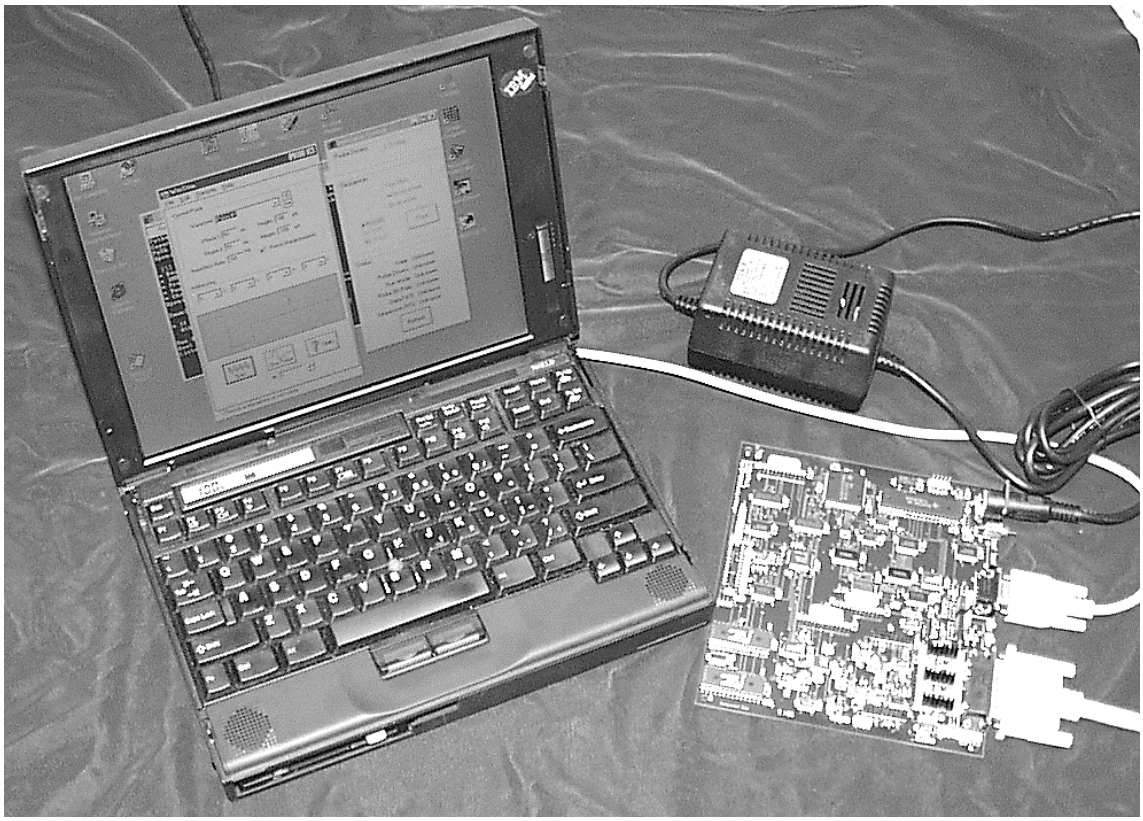

Fig. 10: The complete external interface system: interface software running on a PC laptop, serial cable connection to the printed circuit board, off-the-shelf power supply, and Sun Video Cable connection to remote probe connection.

We are currently working on upgrading the system software to support the STIM-3B protocol, which requires the capability to drive the daisy chain address line simultaneously with the site address line. The necessary hardware is included on the printed circuit board, but we have yet to complete the software to implement the

necessary protocols. This is not a big task and we expect to have the STIM-3B communication protocol supported in the very near future.

In the coming quarter, we plan to complete the design and fabrication of the cable termination/probe connector board. We also expect to have the software in place to support the STIM-3B array communication protocol. We will also likely begin looking into the developing the software to support the STIM-2/3 probes with this same external interface.

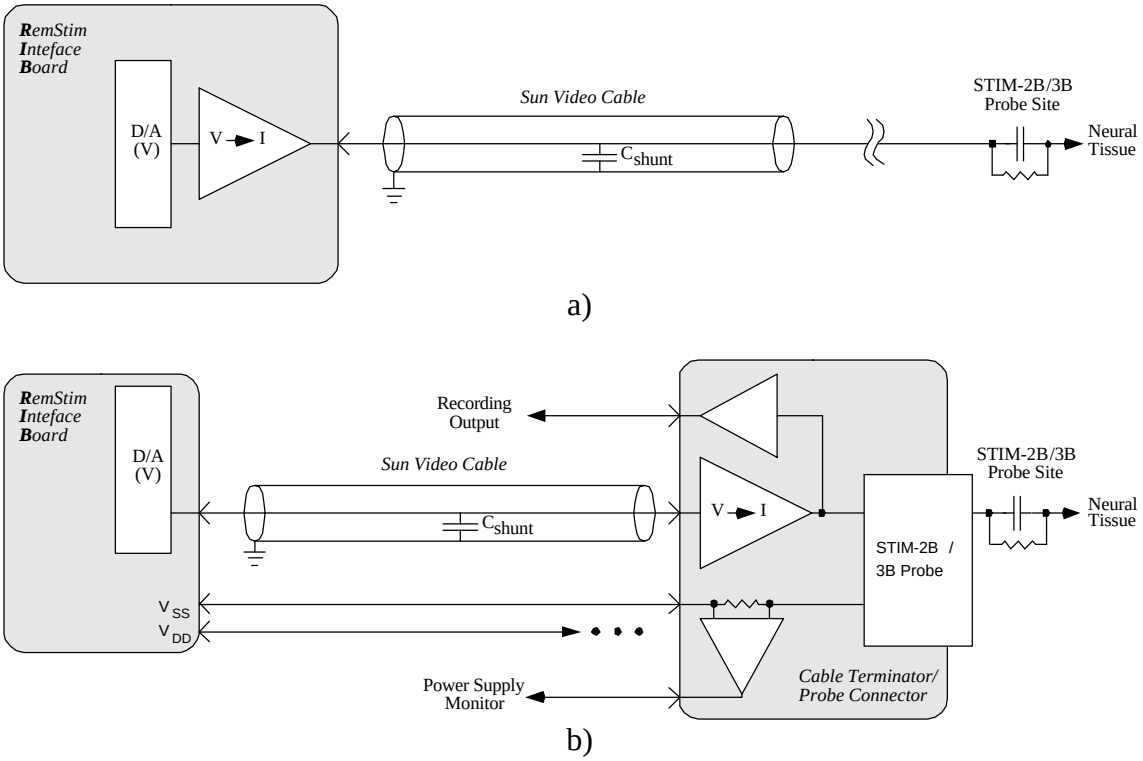

Fig. 11: a) The problematic configuration of the cable connection to the probes. b) the solution to the cable connection to the probes, including some of enhancements.

5. Conclusions

This contract seeks to develop a family of thin-film stimulating arrays for use in neural prostheses. During the past quarter, work has gone forward in a number of areas. Titanium nitride has been reported to have a higher charge delivery capability than iridium oxide and we are exploring this possibility. We have fabricated passive stimulating probes with TiN sites and are comparing them to probes with IrO sites in terms of their ability to deliver charge to tissue. The TiN sites have been shown to be compatible with the usual probe process and offer a potentially more stable site material that is more commonly available in the microelectronics industry. Charge delivery under pulsed conditions will be reported in the next quarterly report and compared with IrO.

During the past term, the first active STIM-3B arrays have been assembled and tested. The arrays are fully functional and are now being readied for in-vivo tests. Several four-probe arrays having 256 sites and 16 parallel channels have been realized. In addition, passive prototype versions of the STIM-2/3 probes have been fabricated and assembled in 3D multi-probe arrays using the STIM-3B mounting hardware. Using flexible interconnect sections between the probe shanks and the circuit area, it has been shown that the circuitry can be folded flat against the cortex to reduce the height of the implant in chronic situations. Finally, the external user interface for the probes has been fabricated in a printed-circuit-board version and has been used with the STIM-2B probes in in-vivo tests. Fine tuning of the external system in both hardware and software is now underway as a basis for supporting the needs of internal and external active probe users.